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Relative Efficiency of a Two-Hinged and a Three-Hinged Arch

Civil Engineering

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RELATIVE EFFICIENCY

OF

A TWO-HINGED AND A THREE-HINGED ARCH

BY

RALPH MARKS BURKHALTER

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

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C O L L E G E O F E N G I N E E R I N G

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This is to certify that the following thesis prepared under the immediate direction of Mr. C. W. Malcolm, Associate in Structural Engineering, by

RALPH MARKS BURKHALTER

entitled THE RELATIVE EFFICIENCY OF A TWO-HINGED AND A THREE-HINGED Concrete ARCH

is accepted by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering.

Ira O. Baker.

Head of Department of Civil Engineering

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The Relative Efficiency of a Two-hinged and a Three-hinged Arch.

The purpose of this thesis is to compute the relative efficiency of a two-hinged and a three-hinged arch under the conditions usually found in trainsheds and mill buildings.

The conditions governing this design were as follows: The train shed was to be 400 feet long, and was to contain seven tracks and suitable foot ways. A heavy masonry wall was to be built to the level of the end pins, and was to be of sufficient height, about seven feet above the base of the rail, to permit the utilization of the entire enclosed floor space for tracks. The minimum headroom allowed, from base of rail to lower chord, was 30 feet. The building was to be provided with side walls and a roof covering, a skylight being required at the apex of the roof.

The span necessary for such a building was taken equal to 125'-0" center to center of end pins. The spacing allowed, center to center of tracks, was alternately 10 and 20 feet. This provided for five foot ways, each 12 foot wide, one on each side of the trainshed and three interspersed between tracks. The masonry walls projected inward 2½ feet to insure stability. The rise for this span was taken as 50'-0", which agrees with the best examples found in practice.

It was decided to use a parabolic truss of the accompanying design, see page 26, for both the two-hinged and the three-hinged arch. It was the object of the writer to design economically and to compute the weight of each type of arch, the ratio of these weights to be considered as the relative efficiency of the two types.

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The design, as shown on the accompanying plates, was adopted after a careful study of numerous examples of similar structures in use.

The specifications used are those given in Ketchum's Mill Buildings. The loads to be determined were the dead load, snow load, and wind load. Since the dimensions were constant, the loads were the same for both types. The dead load consists of the truss itself and the roof covering. The weight of the truss is computed from a formula given by Johnston in his "Framed Structures" In the chapter on arches, he gives the formula, $T = \frac{1}{24} bL^2$, where T is the total weight of the truss, b is the distance, center to center of trusses, and L is the span; b and L being in feet, and T in pounds.

$$T = \frac{1}{24} \times 25 \times 125^2$$

$$T = 16300 \text{ lbs.}$$

The weight of one-half of the span is 8200 pounds. This is considered entirely upon the upper chord, and is accordingly divided into six parts; since there are six upper panel points. This gives 1400 pounds as the panel load due to the weight of the truss. The weight of the roofing and sheathing was taken from "Ketchum's Mill Buildings" previously referred to. Flat tile roofing was used, the weight being 20 pounds per square foot. This was carried by one inch yellow pine sheathing, the weight of which was 4 pounds per square foot. The weight of the steel purlins and rafters supporting this roof was computed from a rough design to be 2 pounds per square foot of roof surface The total weight of roofing was 26 pounds per

square foot of roof surface.

Panel load due to roofing =

$26 \times 13.6 \times 25 = 8900$ pounds.

Adding to this the panel load due to the weight of the truss, we have,

$8900 + 1400 = 10\,300$ pounds, which is the dead panel load.

Both a maximum and a minimum snow load were used, the latter was considered as acting simultaneously with the wind load, the former effective only in the absence of wind. The values used agree with the best practice for a location which has a climate similar to that of Chicago. They are, 30 pounds per square foot of horizontal roof surface for a maximum and 10 pounds per square foot of horizontal roof surface for a minimum.

$30 \times 12.5 \times 25 = 9400$ = maximum snow panel load.

$10 \times 12.5 \times 25 = 3100$ = minimum snow panel load.

The wind load was obtained from Duchemin's formula as given in the specifications:

$P_n = P \frac{2 \sin A}{1 + \sin^2 A}$, where P_n is the pressure normal to the roof, P is the horizontal wind pressure, and A is the angle of inclination of the roof surface. In accordance with the building laws of New York, Boston and Chicago, and in accordance with general railway practice, 30 pounds per square foot was used as the horizontal wind pressure. Substituting the values of P and A in the above formula and solving, we find. $P_n = 20.5$ pounds per square foot of roof surface, which is the normal wind pressure.

$20.5 \times 13.65 \times 25 = 7000$ pounds, which is the wind panel load on the roof surface acting normal to the plane of the roof.

$30.0 \times 7.5 \times 25 = 5600$ pounds, which is the wind panel load on the vertical side of the arch. The point at the eave was considered as receiving one-half of a panel load from each of the intersecting planes.

As previously stated a skylight was required at the apex of the roof. The computed weight of the skylight and purlins was 1800 pounds, and the weight of the truss members was 1400 pounds; therefore, the dead panel load was 3200 pounds. For ease of computations, the snow panel load was taken to be of the same ratio to the dead panel load at this point, as it was at the other panel points. The wind load was assumed to be 2500 pounds, and was considered to be acting vertically.

The Three-Hinged Arch

On plate 1 are shown the stress diagrams for the three-hinged arch under the loads determined above. The stresses obtained from the diagrams were combined to give the maximum stresses as shown on page 11. The members were designed to take these stresses with unit stresses not exceeding $16000 - 70\frac{L}{r}$ as required by the specifications. $\frac{L}{r}$ is the ratio of the length of the member to its least effective radius of gyration. The limit of this ratio and the minimum allowed section, as provided for in the specifications, were observed wherever

they governed the design. Stiff members were used throughout. The actual sections as designed are given on page 12.

The Two Hinged Arch

The two hinged arch was of the same design and general dimensions as the three hinged type, with the exception of the bracing at the apex.

On page 25 are shown diagrams for the various conditions of loading, which give the stresses in the arch considered as a simple truss with one end fixed and the other on rollers. On the following page is a diagram of the stresses in the arch when acted upon by a horizontal load at the roller end.

The method of computing the stresses in a two hinged arch is, briefly, as follows: The stresses are found for the various loads considering the arch as a simple truss. These loads would produce horizontal deformation in the roller end of the truss; but since there is no such motion there must be supplied a horizontal reaction sufficient to produce equilibrium, that is, to produce equal and opposite deformation.

To obtain this horizontal reaction, it is first necessary to assume sections for the various members, then to compute the deformation in each member due to the imposed load. These deformations are multiplied by the ratio $\frac{L}{l}$, where L is the horizontal load applied at the end pins, and l is the stress in each member due to that horizontal load. The sum-

mation of these deformations under any condition of loading is the total movement of the roller end under that load. The deformation due to an assumed horizontal load acting at the end pins are then computed and multiplied by the ratio $\frac{s}{L}$. The summation of these last deformations is to the total deformation due to the loading previously considered, as the assumed horizontal reaction is to the true horizontal reaction corresponding to that loading.

The combined effect of the imposed loads and of the true horizontal reaction will give the actual stresses in the arch.

The deformation in any member is obtained from the formula:

$\Delta = \frac{PUL}{E}$, where, Δ is the deformation, P is the unit stress under the loading considered, U is the ratio $\frac{s}{L}$ as given above and E is the modulus of elasticity. The value of U for each member is obtained from the stresses due to the horizontal load H.

The fundamental theory of the two-hinged arch computation is, as previously stated,

$H_H : H_D :: \Delta_H : \Delta_D$

H_H is the assumed horizontal reaction.

H_D is the true horizontal reaction due to imposed load.

Δ_H is the total deformation due to H_H

Δ_D is the total deformation due to the imposed load.

$\Delta = \Sigma \frac{PUL}{E}$.

It is evident that $\frac{UL}{E}$ is independent of the area of the members, and is constant for each member

In the following discussion, let the members be designated by numbers used as subscripts. Let $C = \frac{ul}{E}$, C_1 being the value of $\frac{ul}{E}$ for member 1, C_2 for member 2, etc. Let S indicate the total stress in the member due to the assumed horizontal load, and let R be the total stress in the member due to the system of loads considered. Let the area for the first design be designated by A, and for the second design by a.

The equations here given are statements of the value of Δ as obtained by the fundamental theory already discussed. Δ_H and Δ_D are deformations in the first design; Δ_h and Δ_d are deformations in the second design.

$$(1) \quad C_1 \frac{S_1}{A_1} + C_2 \frac{S_2}{A_2} + C_3 \frac{S_3}{A_3} + C_4 \frac{S_4}{A_4} + \cdots = \Delta_H$$

$$(2) \quad C_1 \frac{S_1}{a_1} + C_2 \frac{S_2}{a_2} + C_3 \frac{S_3}{a_3} + C_4 \frac{S_4}{a_4} + \cdots = \Delta_h$$

$$(3) \quad C_1 \frac{R_1}{A_1} + C_2 \frac{R_2}{A_2} + C_3 \frac{R_3}{A_3} + C_4 \frac{S_4}{A_4} + \cdots = \Delta_D$$

$$(4) \quad C_1 \frac{R_1}{a_1} + C_2 \frac{R_2}{a_2} + C_3 \frac{R_3}{a_3} + C_4 \frac{R_4}{a_4} + \cdots = \Delta_d$$

From these series we obtain by inspection that

(1) : (2) :: (3) : (4) which reduces readily to the form

$$(5) \quad \frac{\Delta_D}{\Delta_H} = \frac{\Delta_d}{\Delta_h}.$$

But from the fundamental theory as above,

$$H_H : H_D = \Delta_H : \Delta_D$$

or; $$H_D = H_H \frac{\Delta_D}{\Delta_H},$$ that is, that the

true horizontal reaction corresponding to an imposed load equals the assumed H multiplied by the ratio of the deformations: $\frac{\Delta d}{\Delta h}$ or It is shown by equation (5) on the preceding page that this ratio is constant, and is independent of the areas of the members. Therefore, since this ratio is true for all areas the value of H obtained from the ratio of the deformations in the first design is the true H, and the stresses obtained by its use are the true stresses in the arch.

There were two conditions of wind-load. W_1, as shown on the stress diagram on Plate 2, is the condition of the wind acting on the roller end of the truss; W_2 is the condition of the wind acting on the fixed end of the truss. The stresses obtained from W_1 were considered as the stresses on the windward side, those from W_2 as the stresses on the leeward side.

In the truss here designed, the values of the deformations, as given on the stress sheets, are as follows:-

Dead Load

$\Delta_D = 17.0372$

For $H = 25{,}000$ $\Delta_H = 12.950$

$$H_D = \frac{\Delta_D}{\Delta_H} H = \frac{17.0372}{12.950} 25{,}000 = 33{,}000$$

$$\text{Ratio of stresses} = \frac{33000}{25000} = 1.315$$

This ratio of stresses is constant for this condition of loading, and by it the stresses due to H = 33000 may be directly obtained from the stresses due to the assumed H = 25000.

Minimum Snow Load.

The stresses and deformations due to snow load were obtained by the ratio of snow load to dead load.

Minimum snow load = 0.304 dead load

Ratio of stresses, as above,

$= 0.304 \times 1.315 = 0.395.$

Maximum Snow Load.

Maximum snow load = 0.912 dead load

Ratio of stresses, as above,

$= 0.912 \times 1.315 = 1.200.$

Wind Load

Windward = W_1

$\Delta_{W_1} = 7.4381$

$\Delta_H = 12.956 \qquad H = 25000$

$H_{W_1} = \frac{7.4381}{12.956} 25000 = 14300$

Ratio of stresses, as above,

$\frac{14300}{25000} = 0.573.$

Leeward = W_2

$\Delta_{W_2} = 11.5634$

$\Delta_H = 12.956 \qquad H = 25000$

$H_{W_2} = \frac{11.5634}{12.956} = 22,300$

Ratio of stresses $= \frac{22300}{25000} = 0.891.$

By means of these ratios of stresses, the stresses due to the actual horizontal reactions were obtained throughout. These were combined with the stresses due to the imposed loads. The resultants thus obtained are the actual stresses in the several members. These computations are shown on pages 13 to 20.

From these stresses were obtained the maximum stresses for which the arch was designed according to the specifications.

Conclusion

As shown on the preceding page, the weight, exclusive of details, of the two-hinged arch is 14,902 pounds; while that of the three-hinged arch is 13,456 pounds. The three-hinged arch is the lighter by 1,446 pounds, which is 10.9% of the total weight. This does not agree with the best authority on the subject, it being the almost universal belief that the two-hinged arch is the more economical. The only apparent reason for such a difference between opinion and results is that the design here used was unfavorable to the two-hinged type, although it was not intended or considered so by the writer. Had another design been used, the weight of the two-hinged arch might have been decreased, however, the amount of this decrease would probably not have equalled 10% of the total weight. The time limiting this report did not permit of a redesign. It is, then, the conclusion of this investigation that the three-hinged arch is more economical than the two-hinged arch under conditions similar to ordinary mill building and train shed construction.

THREE-HINGED ARCH

Maximum Stresses

Member	Dead Load	Minimum Snow Load	Maximum Snow Load	Wind Load Leeward	Wind Load Windward	Maximum Stress
AB	-51000	-15300	-48000	-31600	+24000	-99000
BY	-13000	-3900	-11900	+10700	-38100	-55000
BC	00	00	00	00	-5600	-5600
CX	-13000	-3,900	-11900	+10700	-38100	-55000
CD	-2000	-600	-1800	-1300	+5600	-3900
DA	-50500	-15200	-46100	-31300	+19000	-97000
DE	+1300	+400	+1200	+700	-9100	-7800
EW	-15300	-4600	-14000	+9500	-31500	-51400
EF	-4100	-1200	-3700	-2700	+8000	-8000
FA	-50200	-15100	-45700	-31000	+14000	-96300
FH	+10500	+3200	+9600	-5700	+8500	+22200
HG	-10300	-3100	-9400	+11400	-30500	-43900
GV	-10300	-3100	-9400	00	-5200	-19700
GU	00	00	00	00	-4800	-4800
HI	-10800	-3200	-9800	+2500	-5600	-20600
IA	-38800	-11700	-35400	-36000	+22000	-86500
IJ	+10000	+3000	+9200	-12800	+19000	+32000
JT	-13700	-4100	-12500	+21200	-48800	-66600
JK	-13900	-4200	-12700	+3000	-9700	-27800
KA	-28200	-8500	-25800	-45300	+37400	-82000
KL	+11200	+3400	+10200	-7000	+6500	+21400
LS	-20000	-6000	-18300	+27700	-54800	-80800
LM	-9200	-2800	-8400	-5000	+3400	-17600
MA	-17500	-5300	-16000	-50700	+42600	-73500
MN	-800	-200	-700	+12700	-26000	-27000
NR	-15000	-4500	-13700	+16000	-31000	-50500
NO	-2000	-600	-1800	-10000	+13500	-12600
OA	-18400	-5500	-16800	-39200	+18800	-63100
OP	-13000	-3900	-11900	+18700	-37000	-53900
PZ	-3400	-1000	-3100	-2500	-2500	-6900
PQ	00	00	00	00	-1500	-1500

Note: All stresses in this thesis are represented as follows: + = tension; - = compression.

THREE-HINGED ARCH

Design of Sections

Member	Maximum Stress	Length inches	Sections No	Sections Angles	r	Allowed Stress	Area □"	E %
AB	-99,000	112	2	6x4x$\frac{1}{2}$	1.51	10800	9.50	104
BY	-55,000	90	2	$3\frac{1}{2}$x3x$\frac{7}{16}$	1.23	10900	5.30	105
BC	-5,600	66	1	2x2x$\frac{1}{4}$	0.61	8400	0.94	1.41
CX	-55,000	90	2	$3\frac{1}{2}$x3x$\frac{7}{16}$	1.23	10900	5.30	105
CD	-3,900	112	2	$2\frac{1}{2}$x$2\frac{1}{2}$x$\frac{1}{4}$	0.77	6000	1.19	184
DA	-97,000	115	2	6x4x$\frac{1}{2}$	1.51	10600	9.50	104
DE	-7800	138	2	$2\frac{1}{2}$x$2\frac{1}{2}$x$\frac{1}{4}$	1.05	6800	2.38	208
EW	-51,400	90	2	4x3x$\frac{3}{8}$	1.18	10700	4.96	104
EF	-8,000	165	1	4x4x$\frac{5}{16}$	1.24	6700	2.40	200
FA	-96,300	121	2	6x4x$\frac{1}{2}$	1.51	10400	9.50	103
FH	+22,200	221	1	4x3x$\frac{5}{16}$	—	16000	1.49	107
HG	-43,900	216	2	6x4x$\frac{7}{16}$	1.50	5800	8.36	110
GV	-19,700	90	2	$2\frac{1}{2}$x2x$\frac{5}{16}$	0.80	8100	2.62	108
GU	-4,800	164	1	4x4x$\frac{5}{16}$	1.24	6700	2.40	337
HI	-20,600	171	1	4x4x$\frac{7}{16}$	1.23	6300	3.31	101
IA	-86,500	175	2	6x4x$\frac{5}{8}$	1.51	7900	11.72	107
IJ	+32,000	197	1	4x3x$\frac{7}{16}$	—	16000	2.00	100
JT	-66,600	164	2	6x4x$\frac{7}{16}$	1.51	8400	8.36	105
JK	-27,800	108	2	$3\frac{1}{2}$x3x$\frac{5}{16}$	1.20	9700	3.86	130
KA	-82,000	167	2	6x4x$\frac{9}{16}$	1.51	8300	10.62	107
KL	+21,400	180	1	4x3x$\frac{5}{16}$	—	16000	1.47	110
LS	-80,800	164	2	6x4x$\frac{9}{16}$	1.51	8400	10.62	110
LM	-17,600	75	1	3x3x$\frac{5}{16}$	0.92	10200	1.78	103
MA	-73,500	165	2	6x4x$\frac{1}{2}$	1.51	8400	9.50	108
MN	-27,500	178	2	4x3x$\frac{3}{8}$	1.20	5600	4.96	103
NR	-50,500	164	2	5x$3\frac{1}{2}$x$\frac{7}{16}$	1.33	7400	7.06	103
NO	-12,600	71	1	3x3x$\frac{1}{4}$	0.93	10600	1.44	121
OA	-63,100	127	2	5x$3\frac{1}{2}$x$\frac{7}{16}$	1.33	9300	7.06	104
OP	-53,900	150	2	5x$3\frac{1}{2}$x$\frac{7}{16}$	1.33	8100	7.06	106
PZ	-6,900	90	1	$2\frac{1}{2}$x$2\frac{1}{2}$x$\frac{1}{4}$	0.77	7800	1.19	1.34
PQ	-1,500	164	1	4x4x$\frac{5}{16}$	1.24	6700	2.40	1070

TWO-HINGED ARCH

Deformations due to Dead load

Member	Area	Length	Total Stress	P	$\frac{PL}{E}$	U	$\frac{PUL}{E}$
AB	9.50	112	00	00	00	-1.68	-0.0000
BY	5.30	90	-55000	-10400	-0.0359	+1.34	-0.0481
BC	1.88	66	00	00	00	00	00
CX	5.30	90	-55000	-10400	-0.0359	+1.34	-0.0481
CD	1.44	112	00	00	00	-0.04	00
DA	9.50	115	00	00	00	-1.68	00
DE	2.48	138	00	00	00	+0.03	00
EW	4.96	90	-55,000	-11100	-0.0345	+1.313	-0.0453
EF	2.62	165	00	00	00	-0.17	00
FA	9.50	121	00	00	00	-1.68	00
FH	1.44	221	+42,100	+29,200	+0.2220	-1.01	-0.2240
HG	7.22	216	-61,700	-8,450	-0.0630	+1.68	-0.1060
GV	2.62	90	-10,300	-3,930	-0.0122	00	00
GU	8.36	164	00	00	00	00	00
HI	5.50	171	-32,200	-5,860	-0.0346	+0.60	-0.0208
IA	11.72	175	+42,000	+3,580	+0.0216	-2.612	-0.0563
IJ	2.62	197	+86,500	+33,000	+0.2240	-2.22	-0.4970
J.T.	8.36	164	-125,900	-15,050	-0.0850	+3.40	+0.2895
JK	2.86	108	-53,500	-18,720	-0.0696	+1.55	-0.1080
KA	10.62	167	+14,300	-1,070	+0.0620	-4.48	-0.2780
KL	2.72	180	+109,300	+40,200	+0.2492	-3.72	-0.9260
LS	10.62	164	-222,000	-20,850	-0.1181	+6.80	-0.8050
LM	2.12	75	-27,000	-12,730	-0.0330	+0.60	-0.1980
MA	9.50	165	+212,500	+22,400	+0.1272	-7.74	-0.9850
MN	4.96	178	+46,000	+9,270	0.0569	-1.50	-0.0850
NR	7.96	164	-260,000	-32,600	-0.1810	+8.10	-1.4670
NO	1.88	71	+98,000	+52,100	+0.1271	-3.64	-0.4630
O/3	3.00	280	00	00	00	00	00
P/3	12.00	291	-270,000	-22,500	-0.2257	+8.68	-1.9550
PQ	2.88	164	-9,000	-31,200	-0.01762	00	00
AZ	12.00	244	+278000	+23,200	+0.1955	-9.68	-1.8900
					Total = $\Sigma \frac{PUL}{E}$ =		-17,0370

TWO-HINGED ARCH

Deformations due to Wind load W.

Member	Area	Length	Total Stress	P	$\frac{PL}{E}$	U	$\frac{PUL}{E}$
AB	9.50	112	00	00	00	-1.68	000
BY	5.30	90	-16,500	-3120	-0.0100	+1.34	-0.0134
BC	1.88	66	-5,700	-3000		00	00
CX	5.30	90	-16,500	-3120	-0.0100	+1.34	-0.0134
CD	1.44	112	+4500	+3,120	+0.0100	-0.04	-0.0004
DA	9.50	115	-4800	+505	+0.0020	-1.68	-0.0034
DE	2.48	138	-8,000	-3,220	-0.0150	+0.03	-0.0005
EW	4.96	90	-13,000	-2.620	-0.0090	+1.313	-0.0123
EF	2.62	165	+6,000	+2,300	+0.0130	-0.17	+0.0023
FA	9.50	121	-9,100	-960	-0.0040	-1.68	+0.0069
FH	1.44	221	-6,100	-4230	-0.0340	-1.008	+0.0337
HG	7.22	216	-6,100	-834	-0.0060	+1.68	-0.0109
GV	2.62	90	-5,000	-1900	-0.0068	00	00
GU	8.36	164	-4,200	-500	-0.0029	00	00
HI	5.50	171	+5,000	+910	+0.0060	+0.60	+0.0034
IA	11.72	175	-15,200	-1,290	-0.0810	-2,612	+0.2110
IU	2.62	197	-15,800	-6,030	-0.0425	-2.220	+0.0940
UT	8.36	164	+31,00	+370	+0.0022	+3,40	+0.0074
UK	2.86	108	+8,700	+3,040	+0.0117	+1,552	+0.0182
KA	10.62	167	-28,000	-2.640	+0.0157	-4.48	+0.0705
KL	2.72	180	-38200	-14,000	-0.0910	-3.72	+0.3378
LS	10.62	164	+38,200	+3,600	+0.0210	+6.804	+0.1435
LM	2.12	175	+11,700	+5,500	+0.0147	+0.60	+0.0087
MA	9.50	165	-62,700	-6,600	-0.0390	-7.74	+0.0302
MN	4.96	178	-46,700	-9,400	-0.0597	-1.50	+0.0896
HR	7.96	164	+81,200	+10,200	+0.0596	+8.10	+0.4840
HO	1.88	71	-44,100	-23,400	-0.059	-3.64	+0.2180
OB	3.00	280	+59,000	+19,650	+0.1965	00	00
OZ	3.00	280	+59,000	+19.650	+0.1965	00	00
PB	12.00	291	+92.000	+7,660	+0.0797	+8.68	+0.6900
PQ	2.88	164	-3,000	-1,040	-0.0061	00	00
AZ	12.00	244	-178200	-14,850	-0.1290	-9.68	+1.2470
PQ'	2.88	164	-3000	-1,040	-0.0061	00	00
O'N'	1.88	71	-72,900	-38,700	-0.0982	-3.64	+0.3578

TWO-HINGED ARCH

Deformations due to Wind load W,

continued from preceeding page

Member	Area □"	Length inches	Total Stress	P	$\frac{PL}{E}$	U	$\frac{PUL}{E}$
N'M'	4.96	178	- 5,900	-1190	-0,00,76	-1.50	+0,0114
N'R'	7.96	164	+127,800	+16,080	+0,0940	+8.10	+0,7610
M'A'	9,50	165	-158,000	-16,610	-0,0978	-7.74	+0,7570
M'L'	2,12	75	+2,200	+1,040	+0,0028	+0.60	+0.0017
L'S'	10.62	164	+122,500	+11,500	+0,0675	+6.80	+0,4600
K'L'	2,72	180	-52,200	-19,200	-0,1230	-3.72	+0,4590
K'A'	10.62	167	-112,000	-10,600	-0,0630	-4,48	+0,2830
J'K'	2,86	108	+21,100	+7,400	-0,0285	+1,552	+0,0409
J'T'	8,36	164	+74,700	+8,930	-0,0533	+3,40	+0,1780
I'J'	2,62	197	-49,700	-19,000	-0,1335	-2,22	+0,2960
I'A'	11,72	175	-73,000	-6,220	-0,0390	-2,61	+0,1020
H'I'	5,50	171	+13,500	+2,450	+0,0150	+0,60	+0,0090
G'U'	8.36	164	00	00	0,000	0,00	0,0000
G'V'	2.62	90	00	00	0,000	0,00	0,0000
H,G'	7.22	216	+35,000	+4850	+0,0357	+1,68	+0,0630
F'H'	1,44	221	-21,000	-14,600	-0,1150	-1,008	+0,1160
F'A'	9,50	121	-53,300	-5,610	-0,0242	-1,68	+0,0405
E'F'	2,62	165	-3,000	-1,150	-0,0067	-0,17	+0,0012
E'W'	4,96	90	+26,800	+5400	+0,0173	+1,313	+0,0228
D'E'	2,48	138	+1,100	+440	+0,0022	+0,03	+0,0001
D'A'	9,50	115	-53,000	-5,580	-0,0229	-1,68	+0,0385
C'D'	1,44	112	-2,000	-1,380	-0,0056	-0,04	+0,0002
C'X'	5,30	90	+28,200	+5,330	+0,0170	+1,34	+0,0230
B'C'	1,88	66	00	00	00	00	0,0000
B'Y'	5,30	90	+28,200	+5,330	+0,0170	+1,34	+0,0230
A'B'	9,50	112	-53,200	-5,600	-0,0224	-1,68	+0,0375
					$\Sigma \frac{PUL}{E}$		7,4381

TWO-HINGED ARCH

Deformations due to Windload W_2

Member	Area	Length	Total Stress	P	$\frac{PL}{E}$	U	$\frac{PUL}{E}$
AB	9.50	112	+55,500	+5,850	+0,0234	-1.68	-0,0393
BY	5,30	90	-62,000	-11, 700	-0,0376	+1,34	-0,0504
BC	1,88	66	-5,600	-2, 980	-0,0070	00	0.0000
CD	5,30	90	-62,000	-11, 700	-0,0376	+1. 34	-0,0504
CD	1.44	112	+9,000	+6,250	+0,0250	-0,04	-0.0010
DA	9,50	115	+49,300	+5,200	+0,0213	-1, 68	-0,0358
DE	2,48	138	-10,700	-4,310	-0,0212	+0.03	-0.0006
EW	4.96	90	-54,800	-11,050	-0,0395	+1. 31	-0.0518
EF	2.62	165	+9.200	+3, 500	+0,0207	-0,17	-0,0035
FA	9,50	121	+43,500	+4,580	+0:0197	-1, 68	-0.0332
FH	1,44	221	+28,000	+19,400	+0,1535	-1, 01	-0.1550
HG	7.22	216	-60,800	-8,430	-0,0650	+1, 68	-0,1091
GV	2,62	90	- 5,200	-1,980	-0,0063	0.00	0,0000
GU	8.36	164	- 4,200	- 500	-0,0029	0,00	0.0000
HI	5.50	171	-18,100	-3,300	-0,0202	+0,60	-0.0121
IA	11. 72	175	+70,000	+5,960	+0.0374	-2, 61	-0,0975
IU	2.62	197	+64,200	+24,500	+0,1725	-2.22	-0.3830
UT	8.36	164	-114,500	-13,650	-0.0801	+3,40	-0,2370
UK	2.86	108	-33,000	-11, 550	-0,0446	+1. 55	-0.0693
KA	10,62	167	+121, 500	+11, 420	+0.0686	-4,48	-0,3070
KL	2. 72	180	+65,000	+23,900	+0,1535	-3.72	-0.5720
LS	10,62	164	-174,000	-16,400	-0,0961	+6,80	-0,6548
LM	2,12	75	- 7,000	-3,300	-0.0088	+0.60	-0,0053
MA	9,50	165	+178,800	+18,800	+0, 1110	-7.74	-0,8600
MN	4,96	178	+1,000	+ 200	+0.0013	-1,50	-0,0020
NR	7.96	164	-175,300	-22,000	-0. 1290	+8.10	-1.0480
NO	1. 88	71	+68,000	+36,200	+0, 0918	-3.64	-0,3250
OB	3.00	280	+60,000	+20, 000	+0.2000	0,00	0. 0000
OZ	3.00	280	+60,000	+20, 000	+0.2000	0.00	0.0000
PB	12.00	291	-188,000	-15,680	-0,1627	+8.68	-1.4150
PQ	2,88	164	-30,000	-1, 040	-0,0061	0.00	0.0000
AZ	12.00	244	+132,000	+11, 000	+0,0960	+9.68	-9.2801
PQ'	2.88	164	-30,000	-1, 040	-0, 0061	0.00	0.0000
O'N'	1. 88	71	+40,000	+21,250	+0.0540	+8, 68	0.4690

TWO-HINGED ARCH

Deformations due to Wind load W_2
continued from preceeding page

Member	Area □"	Length inches	Total Stress	P	$\frac{PL}{E}$	U	$\frac{PUL}{E}$
N'M'	4.96	178	+36100	+7300	+0.0463	-1.50	-0.0695
N'R'	7.96	164	-127000	-16000	-0.0938	+8.10	-0.7590
M'A'	9.50	165	+87500	+9220	+0.0543	-7.74	-0.4200
M'L'	2.12	75	-14100	-6650	-0.0178	+0.60	-0.0180
L'S'	10.62	164	-93500	-8800	-0.0515	+6.804	-0.3520
K'L'	2.72	180	+50200	+18450	+0.1185	-3.72	-0.4410
K'A'	10.62	167	+42000	+3950	+0.0236	-4.48	-0.1060
J'K'	2.86	108	-21000	-7350	-0.0284	+1.55	-0.0440
J'T'	8.36	164	-47000	-5630	-0.0329	+3.40	-0.1120
I'J'	2.62	197	+34000	+13000	+0.0915	-2.22	-0.2030
I'A'	11.72	175	+13200	+1120	+0.0071	-2.61	-0.0184
H'I'	5.50	186	-10700	-1950	-0.0119	+0.60	-0.0710
G'U'	8.36	164	00	00	0.000	0.00	0.0000
G'V'	2.62	90	00	00	0.000	0.00	0.0000
HG'	7.22	216	-20000	-2770	-0.0214	+1.68	-0.0360
FH'	1.44	221	-13000	+9020	+0.0713	-1.01	-0.0718
FA'	9.50	121	00	00	00	-1.68	00
E'F'	2.62	165	00	00	00	-0.17	00
E'W'	4.96	90	-14700	-2960	-0.0095	+1.313	-0.0125
D'E'	2.48	138	00	00	00	+0.03	00
D'A	9.50	115	00	00	00	-1.68	00
C'D'	1.44	112	00	00	00	-0.04	00
C'X'	5.30	90	-14700	-2780	-0.0089	+1.34	-0.0119
B'C'	1.88	66	00	00	00	00	00
B'Y	5.30	90	-14700	-2780	-0.0089	+1.34	-0.0119
AB'	9.50	112	00	00	00	-1.68	00
						$\Sigma \frac{PUL}{E}$ =	-11.5634

TWO-HINGED ARCH

Deformations under a horizontal load.

Member	Area D"	Length inches	Total Stress	P	$\frac{PL}{E}$	U	$\frac{PUL}{E}$
AB	9.50	112	-42,000	-4,410	-0.0163	-1.68	+0.0274
BY	5.30	90	+33,500	+6,320	+0.0196	+1.34	+0.0263
BC	1.88	66	00	00	0.0	0.0	0.0
CX	5.30	90	+33,500	+6,320	+0.0196	+1.34	+0.0263
CD	1.44	112	-1,000	-690	-0.0034	-0.04	0.0
DA	9.50	115	-42,000	-4,410	-0.0175	-1.68	+0.0294
DE	2.48	138	+700	+280	+0.0013	+0.03	0.0
EW	4.96	90	+32,900	+6,630	+0.0230	+1.313	+0.0310
EF	2.62	165	-4200	-1,600	-0.0091	-0.17	+0.0015
FA	9.50	121	-42,000	-4,410	-0.0184	-1.68	+0.0309
FH	1.44	221	-25,200	-17,500	-0.1335	-1.01	+0.1336
HG	7.22	216	+42,000	+5,820	+0.0434	+1.68	+0.7300
GV	2.62	90	00	00	0.00	0.0	0.0
GU	8.36	164	00	00	0.00	0.0	0.0
HI	5.50	171	+15,000	+2,730	+0.0167	+0.60	+0.1000
IA	11.72	175	-65,300	-5,540	-0.0334	-2.61	+0.0872
IJ	2.62	197	-55,500	-21,200	-0.1455	-2.22	+0.3230
JT	8.36	164	+85,000	+10,300	+0.0582	+3.40	+0.1980
JK	2.86	108	+38,800	+13,520	+0.0504	+1.55	+0.0783
KA	10.62	167	-112,000	-10,500	-0.0604	-4.48	+0.2710
KL	2.72	180	-93,000	-34,000	-0.1570	-3.72	+0.5850
LS	10.62	164	+170,100	+16,000	+0.0905	+6.80	+0.6160
LM	2.12	75	+15,000	+7,070	+0.0183	+0.60	+0.0110
MA	9.50	165	-193,500	-20,200	-0.1150	-7.74	+0.8910
MN	4.96	178	-37,500	-7,560	-0.0464	-1.50	+0.0696
NR	7.96	164	+204,500	+25,700	+0.0145	+8.10	+0.1175
NO	1.88	71	-91,000	-48,300	-0.1181	-3.64	+0.4290
OB	3.00	280	00	00	0.00	0.00	0.0
PB	12.00	291	+217,000	+18,060	+0.1881	+8.68	+1.6300
PQ	2.88	164	00	00	0.00	0.00	0.0
AZ	12.00	244	-242,000	-20,800	-0.1760	-9.68	+1.7000
					Total = $\Sigma \frac{PUL}{E}$	=	12.9560

TWO-HINGED ARCH

Actual Stresses - Dead Load & Snow Load.

Member	Dead Load Arch = a truss	Hor. Reaction for Dead Load	Actual Stress Dead Load	Actual Stress Min. Snow	Actual Stress Max. Snow
AB	00	-55,200	-55,200	-16,700	-49,100
BY	-55,000	+44,000	-11,000	-3,300	-9,900
BC	00	00	00	00	00
CX	-55,000	+44,000	-11,000	-3,300	-9,900
CD	00	-1300	-1,300	-400	-1,200
DA	00	-55200	-55,200	-16,700	-49,100
DE	00	+900	+900	+300	+800
EW	-55,000	+43,200	-11,800	-3,500	-10,800
EF	00	-5,500	-5500	-1,700	-5,000
FA	00	-55,200	-55,200	-16,700	-49,100
FH	+42,100	-33,100	+9,000	+2,700	+82,000
HG	-61,700	+55,200	-6,500	-2,000	-5,900
GV	-10,300	00	-10,300	-3,100	-9,300
GU	00	00	00	00	00
HI	-32,200	+19,700	-12,500	-3800	-11,400
IA	+42,000	-86,000	-44,000	-13,400	-40,000
IJ	+86,500	-73,000	+13500	+4,100	+12,300
JT	-125,900	+112,000	-13,900	-4,200	-12,700
JK	-53,500	+51,000	-2500	-800	-2,300
KA	+114,300	-14,700	-32,700	-9,900	-29,800
KL	+109,300	-122,000	-12,700	-3,900	-11,600
LS	-222,600	+225,000	+3,000	+900	+2,700
LM	-27,000	+19,700	-7,300	-2,200	-6600
MA	+212,500	-254,000	-41,500	-12,600	-38,000
MN	+46,000	-49,300	-3,300	-1,000	-3,000
NR	-260,000	+269,000	+9,000	+2,700	+8200
NO	+98,000	-120,000	-22,000	-6,700	-20,000
OB	00	00	00	00	00
OZ	00	00	00	00	00
PB	-270,000	+295,000	+25,000	+7,600	+22,800
PQ	-9000	00	-9,000	-2,700	-8200
AZ	+278,000	-318,000	-40,000	-12,200	-36,500

TWO-HINGED ARCH

Actual Stresses — Wind Load

Member	Windward			Leeward		
	Stresses Arch = a truss	Hor. Reaction for wind	Actual Stress	Stresses Arch = a truss	Hor. Reaction for wind	Actual Stress
AB	00	+24,100	+24,100	00	-37,400	-37,400
BY	-16,500	-+9,200	-35,700	-14,700	+29,800	+151,00
BC	-5,700	00	-5,700	00	00	00
CX	-16,500	-19,200	-35,700	-14,700	+29,800	+15,100
CD	+4,500	+ 600	+5100	00	- 900	-900
DA	-4,800	+24,100	+19,300	00	-37,400	-37,400
DE	-8,000	- 400	-8400	00	+600	+600
EW	-13,000	-18,900	-31900	-14,700	+29,300	+14,600
EF	+6,000	+2400	+8400	00	-3,700	-3,700
FA	-9,100	+24100	+15,000	00	-37,400	-37,400
FH	-6,100	+14,500	+8400	+13,000	-22400	- 9400
HG	-6,100	-24,100	-18,000	-20000	-37,400	-57,400
GV	-5,000	00	-5,000	00	00	00
GU	-4,200	00	-4,200	00	00	00
HI	+5,000	-8,600	-3600	-10,700	+13400	+2,700
IA	-15,200	+37,400	+22,200	+13,200	- 58,100	+73,900
IJ	-15,800	+31,800	+16000	+34,000	-49,500	-15,500
JT	-31,00	-48,700	-45,600	-47,000	+75,800	+28,800
JK	+8,700	-22,200	-13,500	-21,000	+34,600	+13,600
KA	-28,000	+64,200	+36,200	+42,000	-10,000	+32,000
KL	-38,200	+53,400	+15,200	+50,200	-82,800	-32,600
LS	+38,200	- 97,500	- 59,300	- 93,500	+151, 500	+58,000
LM	+11, 700	- 8600	-3100	-14,100	+13,400	- 700
MA	-62,700	+111000	+49,300	+87,500	-172,500	-85,000
MN	-46,700	+21500	-25,200	+36,100	-33400	+2,700
NR	+81,200	-117,300	-36,100	-127,000	+182,000	+55,000
NO	-44,100	+52,200	+8,100	+40,000	-81,000	-41,000
OB	+59,000	00	+59,000	+60,000	00	+60,000
PB	+92,000	-124,500	-32,500	-188,000	+193,500	+5500
PQ	-3,000	00	-3000	-3,000	00	-3000
AZ	-178,200	+139,000	-39,200	+132,000	-216,000	-84,000

TWO-HINGED ARCH

Maximum Stresses

Member	Area □"	Length "	Dead Load	Minimum Snow	Maximum Snow	Windward W_1	Leeward W_2	Maximum Stress
AB	9.50	112	-55,200	-16,700	-49,100	+24,100	-37,400	-109,300
BY	5.30	90	-11000	-3300	-9,900	-35,700	+15,100	-46,700
B.C.	1.88	66	00	00	00	-5,700	00	-5,700
CX	5.30	90	-11000	-3300	-9,900	-35,700	+15,100	-46,700
CD	1.44	112	-1300	-400	-1,200	+5100	-900	-2600
DA	9.50	115	-55,200	-16,700	-49,100	+19,300	-37,400	-109,300
DE	2.48	138	+900	+300	+800	-8400	+600	-7,500
EW	4.96	90	-11,800	-3,500	-10,800	-31,900	+14,600	-47,200
EF	2.62	165	-5,500	-1700	-5,000	+8,400	-3,700	-10,900
FA	9.50	121	-55,200	-16,700	-50,300	+15,000	-37,400	-109,300
FH	1.44	221	+9,000	+2,700	+8,200	+8,400	-9400	+20,100
HG	7.22	216	-6,500	-2,000	-5,900	+8,000	-57,400	-65,900
GV	2.62	90	-10,300	-3100	-9,300	-5,000	00	-19,600
GU	8.36	164	00	00	00	-4200	00	-4,200
HI	5.50	171	-12,500	-3,800	-11,400	-3,600	+2700	-23,900
IA	11.72	175	-44000	-13,400	-40,000	+22,200	+73900	-84,000
IJ	2.62	197	+13,500	+4100	+12,300	+16,000	-15500	+33600
JT	8.36	164	-13,900	-4,200	-12,700	-45,600	+28,800	-63,700
JK	2.86	108	-2500	-800	-2,300	-13,500	+13600	-16,800
KA	10.62	167	-32,700	-9,900	-29,800	+36,200	+32,000	-62,500
KL	2.72	180	-12,700	-3,900	-11,600	+15,200	-32600	-43,200
LS	10.62	164	+3,000	+900	+2,700	-59,300	+58,000	-56,000
LM	2.12	75	-7300	-2200	-6,600	-3100	-700	-13,900
MA	9.50	165	-41,500	-12600	-38000	49,300	-8500	-79,500
MN	4.96	178	-3300	-1,000	-3,000	-25,200	+2,700	-29,500
NR	7.96	164	+9,000	+2,700	+8,200	-36,100	+55,000	+66,700
NO	1.88	71	-22000	-6,700	-20,000	+8,100	-41,000	-69,700
OB	3.00	280	00	00	00	+60,000	+60,000	+60,000
PB	12.00	291	+25,000	+7,600	+22,800	-32,500	+5,500	+37,500
PQ	2.88	164	-9000	-2700	-8200	-3,000	-3,000	-17,200
AZ	12.00	244	-40,000	-12,200	-36,500	-39,200	-84,000	-136,400

TWO-HINGED ARCH

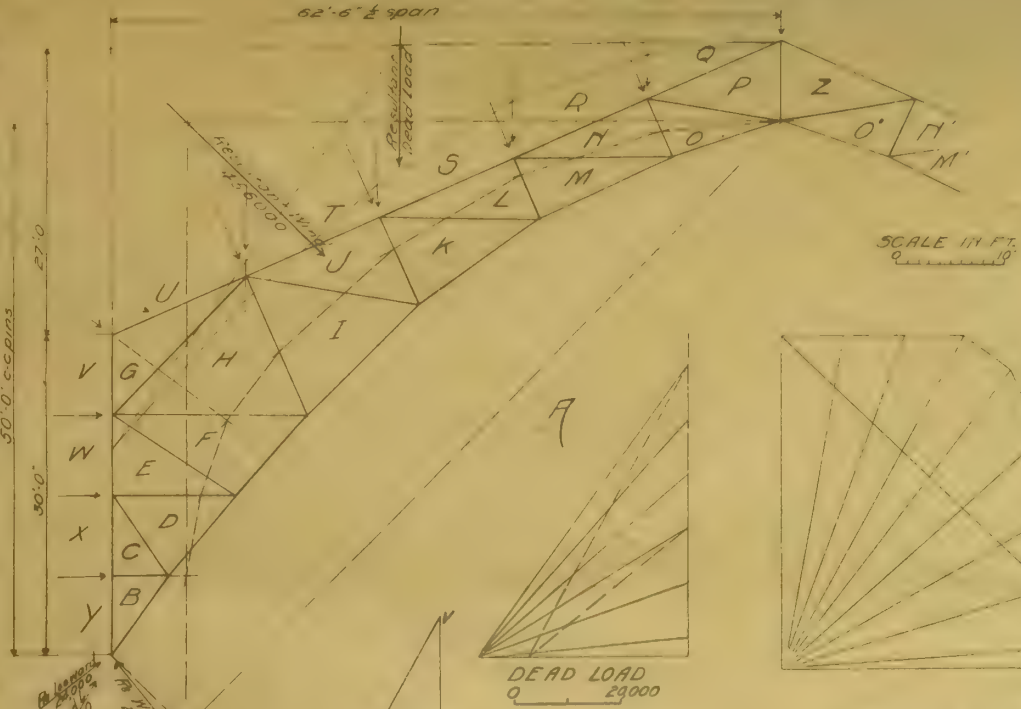
Design of Sections

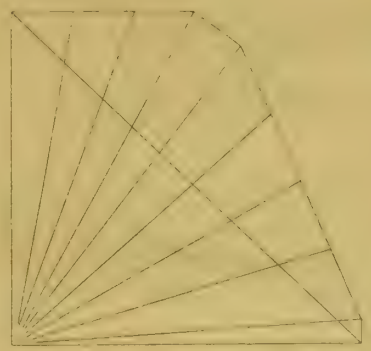
Member	Maximum Stress	Length inches	Sections No	Sections Angles	r	Allowed Stress	Area	E %
AB	-109,300	112	2	6x4x 1/2	1.51	10,800	10.62	105
BY	-46,700	90	1	4x4x 5/8	1.21	10,800	4.61	107
BC	-5,700	66	1	2x2x 1/4	0.61	8,400	0.94	138
CX	-46,700	90	1	4x4x 9/16	1.21	10,800	4.18	107
CD	-2,600	112	1	2 1/2 x 2 1/2 x 1/4	0.77	6,000	1.19	274
DA	-109,300	115	2	6x4x 1/2	1.51	10,700	10.62	104
DE	-75,00	138	1	3x3x 1/4	0.93	5,500	1.44	105
EW	-47,200	90	1	4x4x 5/8	1.21	10,800	4.61	105
EF	-10,900	165	1	4x4x 5/16	1.24	6,700	2.40	147
FA	-109,300	121	2	6x4x 1/2	1.51	10,400	10.62	101
FH	+20,100	221	1	4x4x 3/8	—	16,000	2.11	168
HG	-65,900	216	1	8x8x 1/2	2.50	10,000	7.75	118
GV	-19,600	90	1	3x3x 7/16	0.91	9,100	2.43	124
GU	-4,200	164	1	4x4x 5/16	1.23	6,700	2.40	393
HI	-23,900	171	1	4x4x 9/16	1.21	6,100	4.18	107
IA	-84,000	175	2	6x4x 9/16	1.51	7,900	10.62	100
IJ	+33,600	197	1	6x6x 3/8	—	16,000	3.61	172
JT	-63,700	164	2	6x4x 7/16	1.51	8,400	8.36	110
JK	-16,800	108	1	3x3x 7/16	0.91	7,700	2.43	111
KA	-62,500	167	2	6x4x 7/16	1.51	8,200	8.36	110
KL	-49,200	180	2	5x3 1/2 x 1/2	1.36	6,750	8.00	110
LS	-56,000	164	2	5x3 1/2 x 1/2	1.36	7,500	8.00	107
LM	-13,900	75	1	3x3x 1/4	0.93	10,400	1.44	108
MA	-79,500	165	2	6x4x 1/2	1.51	8,350	9.50	100
MN	-29,500	178	1	6x6x 5/8	1.88	9,400	4.36	139
NR	+66,700	164	1	6x6x 7/16	—	16,000	4.19	100
NO	-69,700	71	1	6x6x 1/2	1.86	13,300	5.75	108
OB	+60,000	280	1	6x6x 7/16	—	16,000	4.19	111
PB	+37,500	291	1	4x4x 5/16	—	16,000	7.78	150
PQ	-17,200	164	1	4x4x 3/8	1.23	6,700	2.86	111
AZ	-136,400	244	2	6x4x 3/4	2.81	9,900	13.88	101

COMPARISON OF WEIGHTS

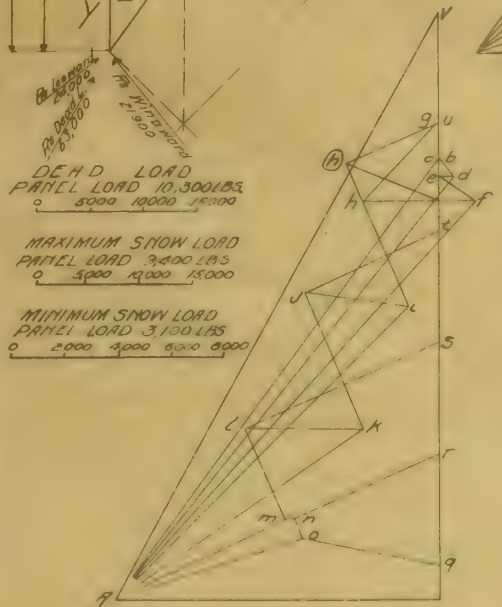
The sections and weights of members in both types.

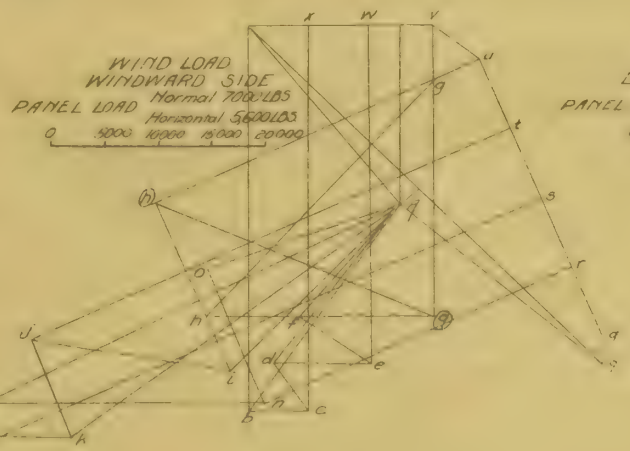
Member	Length Ft.	THREE-HINGED Sections	Weight per ft.	Total Weight	TWO-HINGED Sections	Weight per ft.	Total Weight
AB	9.35	2 L's 6x4x 1/2	32.4	309.5	2 L's 6x4x 1/2	32.4	309.5
BY	7.50	2 L's 3 1/2 x 3 x 7/16	18.2	136.2	1 L 4x4x 5/16	15.7	117.8
BC	5.50	1 L 2x2x 1/4	3.2	17.6	1 L 2x2x 1/4	3.2	17.6
CX	7.50	2 L's 3 1/2 x 3 x 7/16	18.2	136.2	1 L 4x4x 3/16	14.3	107.2
CD	9.35	1 L 2 1/2 x 2 1/2 x 1/4	4.1	38.3	1 L 2 1/2 x 2 1/2 x 1/4	4.1	38.3
DA	9.60	2 L's 6x4x 1/2	32.4	317.0	2 L's 6x4x 1/2	32.4	317.0
DE	11.50	2 L's 2 1/2 x 2 1/2 x 1/4	8.2	94.5	1 L 3x3x 1/4	4.9	56.5
EW	7.50	2 L's 4x3x 3/8	17.0	127.9	1 L 4x4x 5/16	15.7	117.8
EF	13.75	1 L 4x4x 5/16	8.2	112.6	1 L 4x4x 5/16	8.2	112.6
FA	10.10	2 L's 6x4x 1/2	32.4	327.0	2 L's 6x4x 1/2	32.4	327.0
FH	18.40	1 L 4x3x 5/16	7.2	132.2	1 L 4x4x 3/8	9.8	180.5
HG	18.00	2 L's 6x4x 7/16	28.6	512.0	1 L 8x8x 1/2	26.4	475.0
GV	7.50	2 L's 2 1/2 x 2 x 7/16	9.0	67.5	1 L 3x3x 7/16	9.8	73.5
GU	13.65	1 L 4x4x 5/16	8.2	112.0	1 L 4x4x 5/16	8.2	112.0
HI	14.22	1 L 4x4x 7/16	11.3	161.0	1 L 4x4x 9/16	14.3	204.0
IA	14.57	2 L's 6x4x 5/8	40.0	580.5	2 L's 6x4x 9/16	36.2	528.0
IU	16.40	1 L 4x3x 7/16	9.8	160.9	1 L 6x6x 3/8	14.9	244.0
JT	13.65	2 L's 6x4x 7/16	28.6	390.0	2 L's 6x4x 7/16	28.6	390.0
JK	9.00	2 L's 3 1/2 x 3 x 5/16	13.2	118.6	1 L 3x3x 7/16	8.3	74.8
KA	13.90	2 L's 6x4x 9/16	36.2	502.0	2 L's 6x4x 7/16	28.6	398.0
KL	15.00	1 L 4x3x 7/16	7.2	108.0	2 L's 5x3 1/2 x 1/2	27.2	408.0
LS	13.65	2 L's 6x4x 9/16	36.2	493.5	2 L's 5x3 1/2 x 1/2	27.2	371.0
LM	6.25	1 L 3x3x 5/16	6.1	38.2	1 L 3x3x 1/4	4.9	30.6
MA	13.75	2 L's 6x4x 1/2	32.4	445.0	2 L's 6x4x 1/2	32.4	445.0
MN	14.81	2 L's 4x3x 3/8	17.0	252.0	1 L 6x6x 3/8	14.9	221.0
NR	13.65	2 L's 5x3 1/2 x 7/16	24.0	326.7	1 L 6x6x 7/16	17.2	235.0
NO	5.91	1 L 3x3x 1/4	4.9	29.0	1 L 6x6x 1/2	19.6	115.6
OB	23.30	Not in Three-hinged.			1 L 6x6 7/16	17.2	401.0
PB	24.19	" "	" "	" .	1 L 4x4x 5/16	8.2	198.0
PQ	13.65	1 L 4x4x 5/16	8.2	112.0	1 L 4x4x 3/8	9.8	135.0
AZ	20.33	Not in Three-hinged.			2 L's 6x4x 3/4	47.2	958.0
PZ	7.50	1 L 2 1/2 x 2 1/2 x 1/4	4.1	30.6	Not in TWO-hinged.		
OP	12.50	2 L's 5x3 1/2 x 7/16	24.0	300.0	" "	"	" .
OA	10.60	2 L's 5x3 1/2 x 7/16	24.0	254.5	" "	"	" .
	4.00				1 L 4x4x 1/2	12.8	51.2
		Total		6,743.0			
				2			8,823.5
				13486.0			2
		Deduct counted twice		30.0			17647.0
		Weight of main mem.		13456.0			2745.0
					Wt. main mem.		14902.0

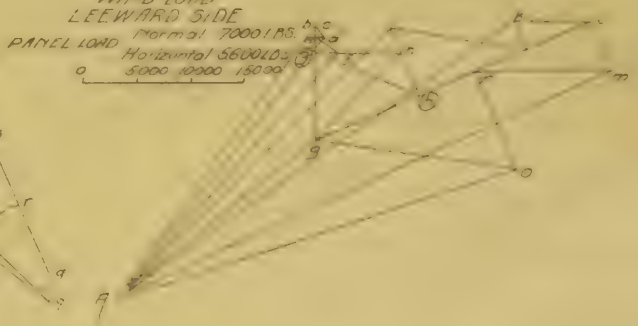




STRESS DIAGRAMS
FOR A
THREE-HINGED ARCH
SPAN - 125'-0" RISE - 50'-0"





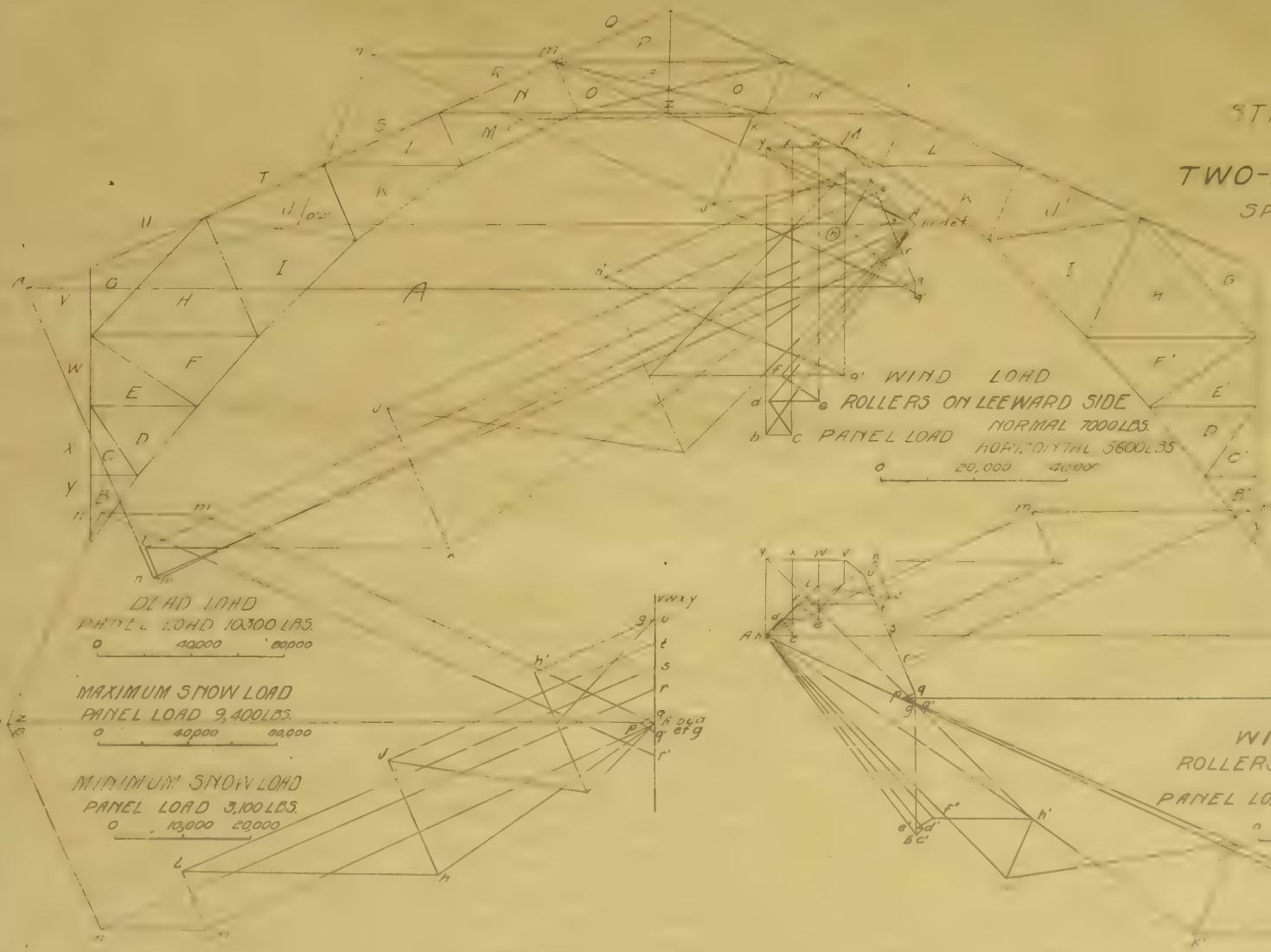


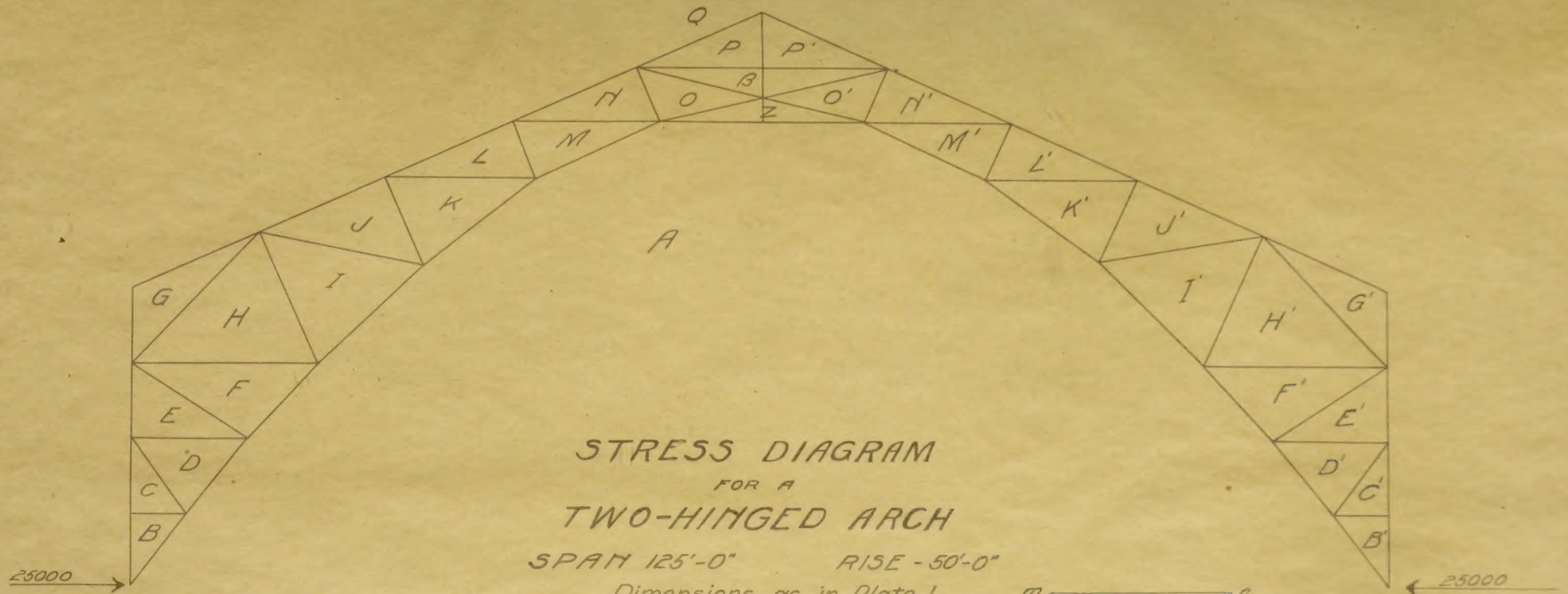
STRESS DIAGRAMS FOR A TWO-HINGED ARCH

SPAN 125'-0" RISE 50'-0"

Dimensions as in Plate I

Arch is considered as simple truss one end on rollers

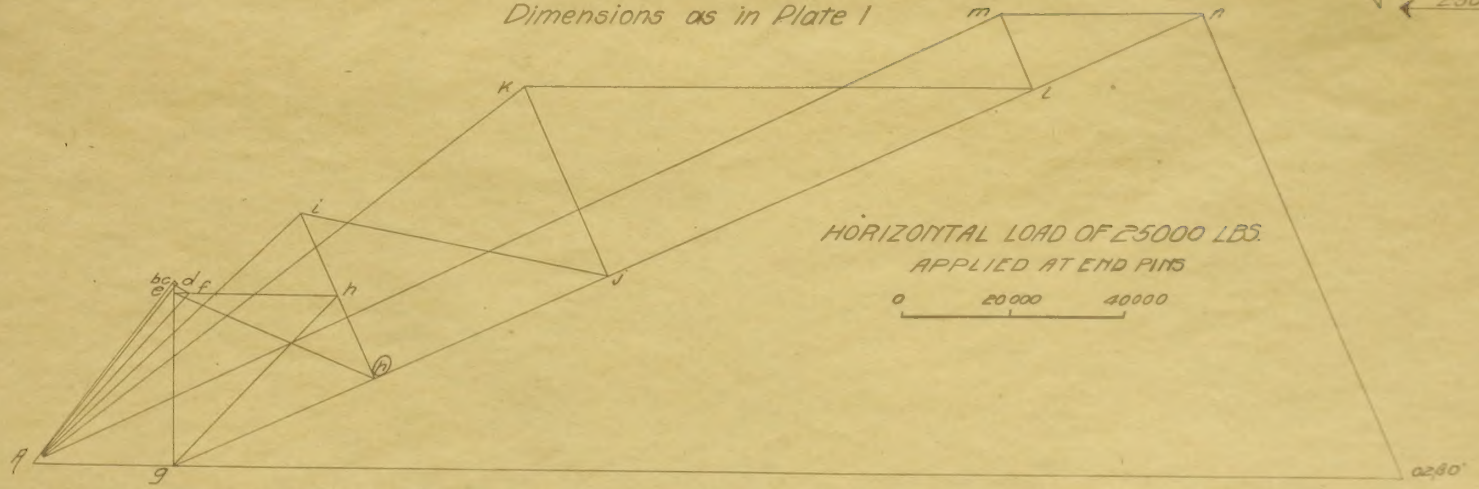




STRESS DIAGRAM
FOR A
TWO-HINGED ARCH

SPAN 125'-0" RISE - 50'-0"

Dimensions as in Plate I



HORIZONTAL LOAD OF 25000 LBS.
APPLIED AT END PINS

0 20000 40000

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